Piezoelectric-based Large-angle Stroke Fast Steering Mirror with High Precision and Self-sensing Capability

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Abstract

In space optical applications, the piezoelectric-actuated fast steering mirror (FSM) is one of the pivotal components for high-precision beam capturing and trajectory tracking. The FSM is restrained in small-angle scanning applications due to the short actuation stroke of the incorporated piezoelectric materials. This study introduces a dual-axis sub-radian stroke FSM with high precision and self-sensing capability, based on cascading structures for displacement amplification. Experimental results reveal that both axes can rotate 148.67 mrad, comparable to existing electromagnetic FSMs.

1 Introduction

The Fast steering mirror (FSM) is a type of mirror that can rapidly and accurately adjust its angular position to compensate for small movements or control vibrations in an optical system. The recent rapid development of laser applications in space further requires fast steering mirrors (FSMs) to operate with large tilt stroke, and high precision in fulfilling laser beam adjustment, target tracking, and scanning [1]. Existing FSMs with large tilt stroke characteristic maily based on the electromagnetic actuation, and their control accuracy, output resolution, and system stiffness are limited by the inherent features of non-contacting driving components[2,3]. By cascading two-stage amplification mechanisms and deflection adjustment mechanisms, respectively, the proposed mirror realizes the large tilt stroke around two orthogonal directions.

2 Structural design

To realize a large fast steering range and high-precision feedback based on piezoelectric actuators, we incorporate the deformation amplification structure with self-sensing units. The overall structure of the proposed FSM is shown in Fig. 1. By cascading four two-stage amplification mechanisms and two deflection adjustment mechanisms, the proposed mirror can realize a large tilt stroke. The strain gauges bonded to the side of the strain-sensing beams are used as sensing units for evaluating the structure deformation and providing real-time feedback. With this design, a novel cascading amplification mechanism is formed, and the sub-radian range tilt motions of the mirror around both the X-axis and Y-axis can be achieved.

3 Experiment

With detailed design of stiffness modeling, dynamic analysis, and finite element analysis for the proposed structure, the prototype of the proposed FSM is manufactured and the experimental setup shown in Fig. 2(a) is build to test the performance. Then, the kinematic performance tests, and closed-loop trajectory tracking experiments are described, and some results is present in Fig. 2. Experimental results reveal that both axes can rotate 148.67 mrad under the closed-loop control, with the ratio of output range to resolution larger than 3.90×10^4, superior to existing FSMs. The further designed experiments of tracking complex trajectories that the accuracy remains lower than 0.02 %.

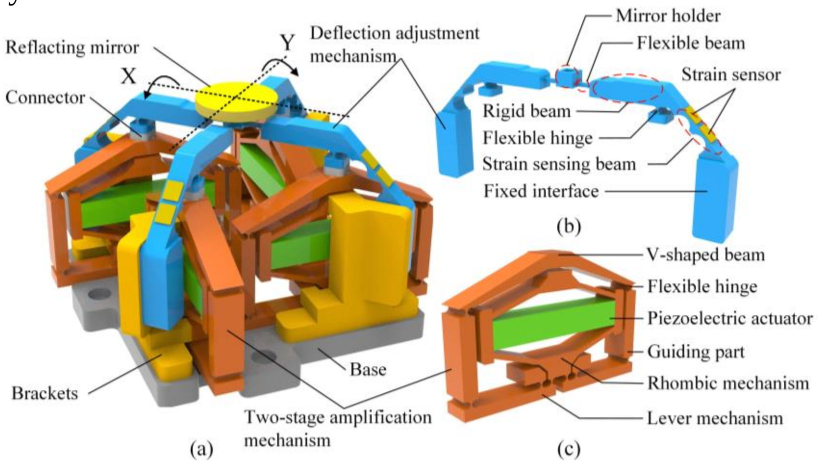

Fig. 1. Schematic of the proposed fast steering mirror. (a) Three-dimensional model. (b) Details of the deflection adjustment mechanism. (c) Details of the two-stage amplification mechanism.

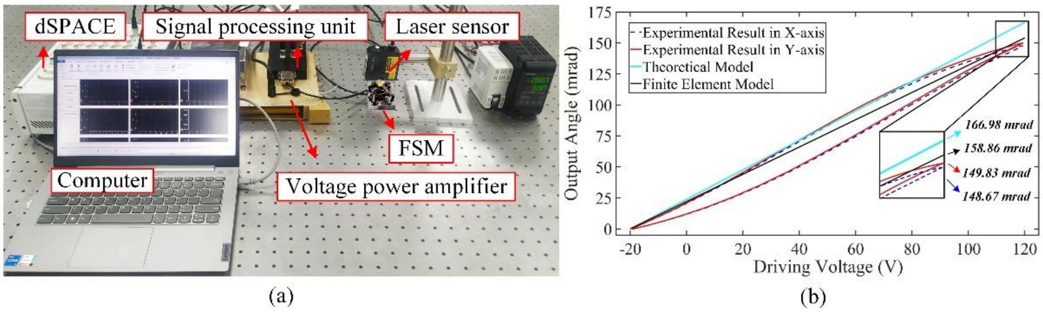

Fig. 2. Schematic of the proposed fast steering mirror. (a) Three-dimensional model. (b) Details of the deflection adjustment mechanism. (c) Details of the two-stage amplification mechanism.

4 Conclusion

To meet the demand of space applications involving high-precision laser beam capturing and large-angle adjustment, this study introduces a piezoelectric-actuated FSM with the large-angle stroke, high ratio of output range to resolution, and self-sensing capability. The proposed structure achieves a breakthrough in output range for piezoelectric-actuated FSMs by cascading four two-stage amplification mechanisms and two deflection adjustment mechanisms. Experimental results reveal that the angle of the FSM traveled exceeds 148.67 mrad in both axes. Compared with existing FSMs, the proposed FSM shows clear superiority, supported by the high ratio of tilt range to output resolution.

References

[1] A. Guignabert, T. Maillard, F. Barillot et al, Point ahead mechanism for deep space optical communication development of a new piezo-based fine steering mirror, Proceedings of the 45th Aerospace Mechanisms Symposium, NASA Johnson Space Center, America, 2020, pp.29-42.

[2] D. J. Kluk, M.T. Boulet, D.L. Trumpera, A high-bandwidth, high-precision, two-axis steering mirror with moving iron actuator, Mechatronics, 22 (2012), pp. 257-270.

[3] E. Csencsics, J. Schlarpa, T. Schopf et al, Compact high performance hybrid reluctance actuated fast steering mirror system, Mechatronics, 62 (2019), 102251.